International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 455-466

NUMERICAL SIMULATION OF PLUG VALVE DESIGN PARAMETERS AS PER STANDARDS

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ABSTRACT

Valves are mechanical devices specifically designed to direct, start, stop, mix, or regulate the flow, pressure, or temperature of a process fluid. Plug Valves are commonly used as fluid flow control equipment in many engineering applications. For designing the Plug Valve it is essential to know the numerical calculations involved in getting the basic design parameters like fasteners size, wall thickness etc., This paper describes the modeling and simulation of the plug valve using ANSYS and the results are compared with numerical equations which are required for basic design parameters of plug valve such as Wall Thickness, Torque Calculations, Stem diameter calculation and fastener calculations. It also includes three-dimensional numerical simulations conducted using the CAD tool to facilitate further changes to geometry. Obtained results not only provide the designer with the access to understanding the steps involved in getting basic design parameters of the plug valve but also helps to determine the appropriate methods to design the Plug valve. Furthermore, the results of the three-dimensional analysis can be used to find the Fluid flow inside the plug valve and in design optimization of valve torque.

KEYWORDS: Plug Valve & Design parameters

Received: May 15, 2018; **Accepted**: Jun 05, 2018; **Published**: Jul 11, 2018; **Paper Id**: IJMPERDAUG201847

Original Article

1. INTRODUCTION

A Plug valve is a quarter-turn manual valve that uses a cylindrical or tapered plug to permit or prevent straight-through flow through the body [1]. The plug has a non-circular bore representing regular-port design, this opening is not the same as the area of the inlet and outlet ports of the valve [2]. Plug valves can be applied to both on-off and throttling services. Plug valves are initially designed to replace gate valves since plug valves by virtue of their quarter-turn action can open and close more easily against flow than a comparable gate valve [3]. For this reason, some plug valves designs are built face to face specifications used for gate valves [4].

Plug valves are commonly applied to low-pressure-low-temperature services, although some higher-pressure-higher-temperature designs exist [2]. The design also permits for the easy lining of the body with such material as PTFE for use with corrosive chemical services [3]. They are also ideal for on-off, moderate throttling, and diverting applications. They are applied in liquid and gas, food processing and pharmaceutical services [1-3-4]. Depending upon the required end connection, plug valves are commonly found in size up to 18 in (DN450) [1-3].

ASME Sec VIII Div.2 [14], the rule of this division is used for the construction of Pressure vessels; the scope of this division has been established to identify components and parameters considered in formulating the rules given in this division. ASME B16.5 [15], this standard covers pressure-temperature rating, material, dimensions, tolerances, marking, testing, and methods of designating opening for pipe flanges and flanged fitting. The standard API 598 [18], covers inspection, examination, pressure test requirements for the gate, globe, plug, ball, check, and butterfly valve. ASME B1.11 [19], this standard covers the screw thread used from mounting the objective assembly to the body. BS 5158:1989 [20], this standard specifies the requirement for valve seat and body pressure-temperature rating and for design, including material, dimensions, of cast iron plug valves. Piyush [21], this paper contains design and development of double offset butterfly valve by using ANSYS and numerical calculations.

In this study, the systematic approach of modeling and numerical simulation of plug valve is carried out. This paper gives a brief understanding to designers to calculate the basic design parameters of Plug valve like wall thickness, torque etc., by referring appropriate standards. The design methodology discussed in this work helps to prevent over design or unsafe design of a valve caused by lack of knowledge of appropriate design standards.

2. METHODOLOGY

Table 3 & Figure 1 Shows the bill of material and sketch of the Plug valve of 3 inches 300 class investigated in this study. The key specifications of the valve are mentioned in Table 1 and the nomenclature of the valves is shown in Figure 1. The material of the body taken as ASTM A 216 Gr. WCB a carbon steel material, the properties of the material are shown in Table 2 [5-13].

To perform Static analysis of components solid model is required; all the components are modeled in Solid Works. The boundary conditions applied are inlet pressure as 51 bar [6] and the flanges are in fixed condition.

Table 1: Key Specifications of Valve

Valve Type	Plug Valve
Valve Size	3 Inch
Valve Class	300#
Operating Pressure	51 Bar

Table 2: Material Properties

Young's Modulus	210 GPa
Poisson's Ratio	0.3
Yield Strength	249.2 MPa
UTS	482.6 MPa
Density	7750 (Kg/m3)

Table 3: Part List & Selected Material

Valve Parts	Material
Body (1)	ASTM A 216 Gr. WCB
Guide Plate (2)	ASTM A 105N
Plug (3)	ASTM A 216 Gr. WCB
Bottom Cover (4)	ASTM A 216 Gr. WCB
Stem (5)	17-4PH
Top Cover (6)	ASTM A 105N
Washer (7)	AISI 304

Table 3: Contd.,	
Plug Adjusting Device (8)	AISI 410
Cap	ASTM A 105N
Lever	ASTM A 351 Gr. CF8M
Nut	ASTM A 351 Gr. 2HM
Stud	ASTM A 193 Gr. B7M
Diaphragm	Carbon Steel

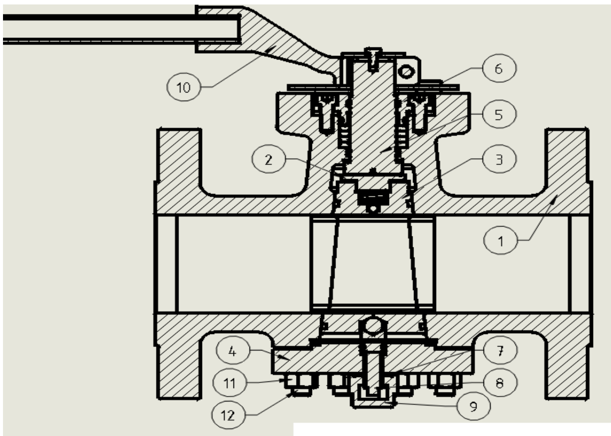


Figure 1: Nomenclature of Plug Valve

3. NUMERICAL ANALYSIS

The first step of design calculation starts with calculating the wall thickness of the body. Minimum wall thickness needs to be maintained is given by various standards as mentioned below.

- BS EN 12516-1 – 2005 industrial valves – this standard specifies the tabulation method for determining the wall thickness of valve bodies with essentially circular cross-section made in forged, cast or fabricated steel.
- As per above standard minimum wall thicknesses is 6.3mm
- ASME B16.34 – 2013 specifies as 7.0 mm
- ASME Section VIII Division 1 – 2013 specifies as 9.5mm
- As per BS EN 12516-2-2004 are appended below.

$$e_c = \frac{d_i \text{ x } p}{(2 \text{ x } S - p) \text{x } K_c} \tag{1}$$

Where

- **S** – Allowable Stresses – 138 MPa [5]
- **P** –Working Pressure – 5.10 MPa [6]
- **Kc** – Welding Factor – 1 (depend upon welding process)
- **di** – Inner Diameter – 76.2 mm

If (di/do) ratio is less than or equal to 1.7 then wall thickness to be calculated by using equation (1). Obtained wall thickness is 1.43 mm and considering Manufacturing & Corrosion allowance. The net wall thickness is 15 mm. Therefore

comparing the wall thickness as the mentioned manufacturer may adopt 15 mm as a minimum wall thickness for the valve body. The cross-section view of the valve body is shown in Figure 2.

3.1. Valve Torque Calculations [1]

Valve torque requirement; in other words, the amount of thrust that the actuator must apply to the shaft to produce rotational force to operate the valve. In particular, the user must calculate the seating torque, which is the torque needed to close the valve against or with the process; the breakout torque, which is the torque needed to begin to open the valve; and the dynamic torque, which is the torque needed to throttle the valve. When these torque valves are known, the correct rotary actuator can be chosen.

While designing designer can choose split type stem or single piece stem design. Both the types have certain own advantages such as single piece design not require any alignment compared to split type. The calculation for single piece stem type is been elaborated below.

The design calculation for stem starts with torque calculations in which the total torque is the addition of various torque required to be overcome while closing or opening of the valve under pressure or with no flow conditions. These various torques are bearing torque, dynamic torque, packing & hub torque, seating torque which is required to overcome for the valve to get open or close. The input values for the calculation for each torque are mentioned as below.

- Maximum diameter of the Plug (D) – 2 Inch
- Minimum diameter of the Plug (d) – 1.37 Inch
- Weight of the plug (W) – 1.72 lbf
- Working Pressure (P) – 5.1MPa
- Allen surface height (s) - 3.58 inch
- Surface Area of the Plug (As) – Equation 2.1

Breakout torque (T) = Ts + Th + Tb (2)

Where

- **Ts** – Seat Torque (lbf-inch)
- **Th** – Hand wheel Torque (lbf-inch)
- **Tb** - Bearing Torque (lbf-inch)

$$A_s = \pi \text{ x } s \text{ x } \frac{(D+d)}{4} \tag{2.1}$$

$$T_s = A_s \text{ x } P_s \text{ x } \mu \tag{2.2}$$

$$T_b = \mu b \text{ x } W \text{ x } \frac{d}{2} \tag{2.3}$$

After Substituting above valves in Equation (2) the breakout torque is 312 Nm. If the final number for the dynamic torque valves is a negative number, the plug will resist closing with the flow moving the disc toward the open position. If the dynamic torque number is positive, the plug will resist opening with the flow moving the plug towards the

closed position.

3.2 Stem Diameter Calculations [10-11]

Stem material is considering as 17-4 PH (ASTM A7.5 Gr. 630) the input parameters for calculating Stem Diameter is as stated below.

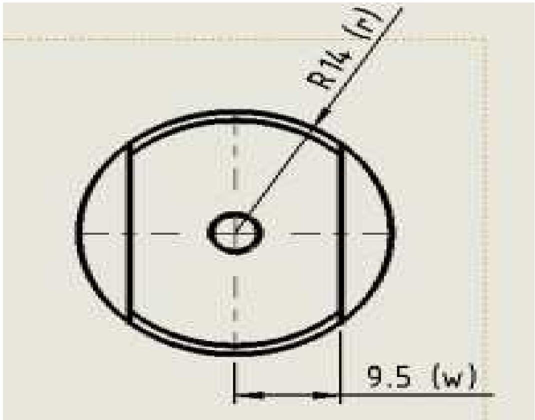
- Breakout Torque (T) – 312 Nm (eq. 2)
- Ultimate Tensile Strength (UTS) – 1000 N/mm2
- Yield Strength (YS) – 725 N/mm2
- Max. Allowable Shear Stress (S) – 480 N/mm2
- Diameter of the Stem (d) – Equation (3)

$$d = \sqrt[3]{\frac{5.1 \text{ x } 2T}{S}} \tag{3}$$

By substituting the above value in equation (3) the stem diameter is selected as 22 mm. The next step would be checking the stem for of shear failure at various week areas of the stem design on Roark's and Young's formula for stress and strain.

- Allowable shear stress obtained from ASME Boiler & Pressure vessel code for stem material – 266MPa
- Diameter of the stem (D) – 22mm (From equation 3)
- Valve torque as calculated above (T) – 312Nm
- For design using factor of safety 2.0 (T) – 624Nm
- for flattened section (h/r) – 0.321428
- B – 1.266 (from equation 4)

Considering circular stem is flattened at edges on both sides we have Roark's equation as [24]



$$B = 0.6366 + 2.6298\,\frac{h}{r} - 5.6147\left(\frac{h}{r}\right)^2 + 49.568\left(\frac{h}{r}\right)^3 - 85.886\left(\frac{h}{r}\right)^4 + 69.849\left(\frac{h}{r}\right)^5$$

Torque transmitted by the circular stem with opposite sides flattened is has to be more than the Actual shear stress of the circular shaft [24]. Then the design is safe for shear failure.

3.3. Bolting Calculations [6]

Since bolting material does not come in contact with the fluid, its material compatibility with fluid is not important. The selection of bolt material is determines based on service conditions. It is important for bolting material to have good tensile stress.

There are two different joints in Plug valve assembly one is Body and top cover joint and the second one is the body and bottom cover joint. Numerical calculations of above mentioned two cases are conducted as per ASME B16.34 standards.

3.3.1 Body & Top Cover Joint

- Pressure rating class (Pc) – 300 [9]
- Allowable bolt stresses at 38°C (Sa) – 137.9 MPa
- Outer diameter of the seal (g) – 35 mm
- Diameter of the selected bolt (d) – 6mm
- Pitch of the selected bolt (p) – 1
- No of bolts (n) – 6
- Cross-sectional area of the selected bolts (Ab) – 121mm2 (Equation 5)
- Area of the seal (Ag) – 961.625 mm2 (Equation 6)

$$\mathrm{Ab} = \frac{\mathrm{n \times \pi \times (d-(0.9382 \times p))^2}}{4} \tag{5}$$

$$\mathrm{Ag} = 0.785 \times \mathrm{g}^2 \tag{6}$$

$$\mathrm{Pc}\left(\frac{\mathrm{Ag}}{\mathrm{Ab}}\right) \leq \mathrm{K1 \times Sa} \leq 9000 \tag{7}$$

$$= 2393 \leq \mathrm{K1 \times Sa} \leq 9000$$

$$= 2392.06 \leq 9000$$

As per above calculations Equation (6) is satisfied hence the M6 bolts are safe to use in Body and top cover joint.

Body & Bottom Cover Joint

- Pressure rating class (Pc) – **300**
- Allowable bolt stresses at 38°C (Sa) – **137.9 MPa**
- Outer diameter of the seal (g) – **63 mm**
- Diameter of the selected bolt (d) – **8mm**
- Pitch of the selected bolt (p) – **1.25**

- No of bolts (n) – 8
- Cross-sectional area of the selected bolts (Ab) – 121mm2 (Equation 4)
- Area of the seal (Ag) – 961.625 mm2 (Equation 5)

Substituting above valves in Equation 4, 5, 6, 6.1 and the results are satisfied hence M8 bolts are safe for the body and bottom cover joint. So as per ASME B16.34 [9] calculations, we find the bolt size for the body and top cover joint and as well as the Body bottom cover joint but now we cross-reference calculation with ASME SEC VIII Div.1.

3.4. Bolting Calculations [9]

There are two different joints in Plug valve assembly one is Body and top cover joint and the second one is the body and bottom cover joint. We have to perform sets of calculations. First Calculations of above mentioned two cases are done by using ASME Sec VIII Div.I standards.

- Internal design pressure (P) – 5.10 MPa
- Allowable Bolt Stresses (Sa) – 138 MPa
- Diameter of the Seal Load reaction (G) – 30mm
- Basic sealing width (b0) – 2.75 mm
- Diameter of the selected Bolt – 6 mm
- Pitch of the selected Bolt – 1
- No. of Bolts – 6
- Joint contact surface unit seating load (y) – 69 MPa (ASEM SEC VIII Div.I)
- Min required bolt load for operating condition (Wm1) – 11286.49 N
- Min required bolt load for the seal seating (Wm2) – 15140.42 N
- Cross-sectional area of bolt (Ab) – 120.68 mm2
- Total required cross-sectional area of the bolt (Am) – 108.26 mm2

$$\mathrm{b} = \mathrm{Min}\ (\mathrm{b_0}, 2.52 \ \mathrm{x} \sqrt{\mathrm{b_0}}) \tag{9}$$

$$\mathrm{Wm1} = (0.785 \ \mathrm{x} \ \mathrm{G^2} \ \mathrm{x} \ \mathrm{P}) + (2 \ \mathrm{x} \ \pi \ \mathrm{x} \ \mathrm{b} \ \mathrm{x} \ \mathrm{G} \ \mathrm{x} \ \mathrm{m} \ \mathrm{x} \ \mathrm{P}) \tag{10}$$

$$\mathrm{Wm2} = \pi \ \mathrm{x} \ \mathrm{b} \ \mathrm{x} \ \mathrm{G} \ \mathrm{x} \ \mathrm{y} \tag{11}$$

$$\mathrm{W} = \mathrm{if}\ (\mathrm{Wm1} > Wm2, Wm1, \left(\frac{\left(\frac{\mathrm{A_m}}{\mathrm{A_b}}\right) \mathrm{x} \ \mathrm{S_a})}{2}\right) \tag{12}$$

$$\mathrm{Ab} = \frac{\mathrm{n} \ \mathrm{x} \ \pi \ \mathrm{x} \ (\mathrm{d} - (0.9382 \ \mathrm{x} \ \mathrm{p}))^2}{4} \tag{13}$$

$$\mathrm{A_m} = \frac{\mathrm{W}}{\mathrm{S_a}} \tag{14}$$

Hence the above condition is satisfied based on case 1 and case 2 the body and top cover joint bolt size is M6x6. And same Body and bottom cover joint M8x8 bolt size is safe for the joint.

4. SIMULATION

A static structural analysis [13] determines the displacements, stresses, strains, and forces in structure caused by the loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed. Finite element analysis is carried out on various parts of Plug valve the parts are the body, plug, bottom cover and top cover.

Finite element analysis is carried out using material Grade in Carbon steel such as WCB. The objects of the analysis are to estimate the maximum stress and to understand the various stresses. and to estimate the maximum deflection and to understand total deflection in various directions.

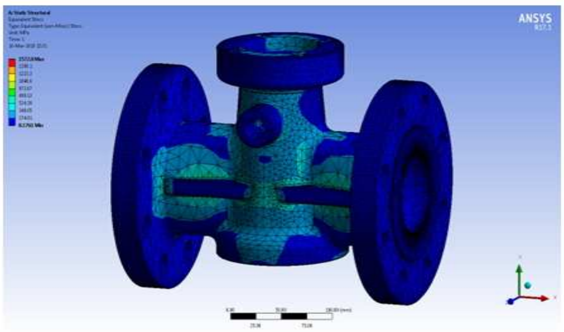


Figure 2: Stress in Body

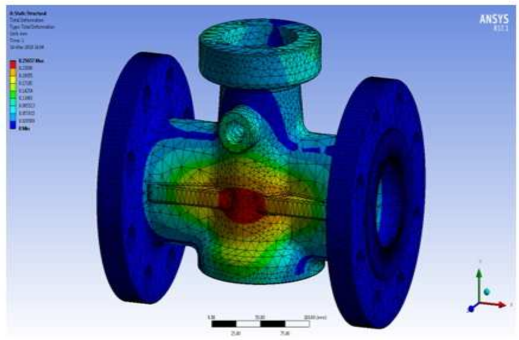


Figure 3: Total Deformation for Body

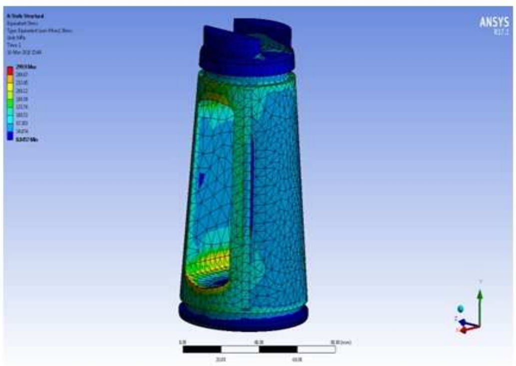


Figure 4: Stress in Plug

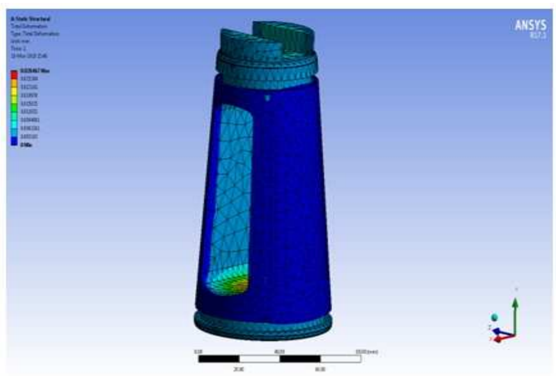


Figure 5: Total Deformation for Plug.

Table 4: Summary of Static Analysis

Valve Parts	Stress/Deformation	Obtained Valves
Body	Stress (MPa)	174.91
	Total Def (mm)	0.256
Plug	Stress (MPa)	200
	Total Def (mm)	0.02846
Bottom Cover	Stress (MPa)	201.24
	Total Def (mm)	0.06757
Top Cover	Stress (MPa)	216.94

	Total Def (mm)	0.02666

5. CONCLUSIONS

This paper presents a systematic approach to numerical simulation of plug valve design parameters including the modeling and numerical calculations. The obtained results are shown in Table 4 & 5. In order to confirm these results, experimental testing is performed with these results obtained from the calculated values of torque and thickness. Experimental results found satisfactory.

Obtained Von Mises stress induced in the parts of the Plug valve of applied pressure is less than the yield strength of the material. Hence the design of the plug valve for the chosen material is safe.

Table 5: Results Obtained from Numerical Calculations

Wall Thickness	15 mm
Selected Stem Diameter	22 mm
Breakout Torque	312 Nm
Flange Thickness	15mm
Bolting (Body & Top cover)	M6 x 6
Bolting (Body & Bottom Cover)	M8 x 8

NOMENCLATURE

S	: Allowable Stress		
P	: Working Pressure	Pc	: Pressure Rating Class.
Kc	: Welding Factor	G	: Diameter of the Seal Load.
Di	: Inner Diameter (Bore)	m	: Seal Factor.
T	: Breakout torque	n	: No. of Bolts.
Ts	: Seat Torque	Wm1	: Min. Required Bolt Load for the Operating Condition.
Th	: Hand wheel torque	Wm2	: Min. required bolt load for the seal seating.
As	: Surface Area of the Plug	W	: Flange design bolt load.
μ	: Seat coefficient of friction	Sa	: Allowable bolt stresses.
d	: Diameter of the Stem	μb	: Bearing coefficient of friction.
Ag	: Area of Seal	ec	: Wall thickness.
Ab	: Cross sectional area of the selected Bolt.		

ACKNOWLEDGEMENT

Our sincere thanks to Mr. Javed A. Hawa, Managing Director of Hawa Valves India Pvt. Ltd. who encouraged and allowed to present this paper.

We would like to express our thanks to Mr. Kishore K (Design In-charge, Hawa Valves India Pvt. Ltd) & Mayur Bhandari (Sr. Engineer, Hawa Valves India Pvt. Ltd) for their helping when ever needed.

We also thank Mr. Chitta Nageswara Rao, (M.Tech, and M.B.A) for motivating and providing guidance.

ABOUT COMPANY

Hawa Valves are manufacturers and exporters of valves for application in critical hydrocarbon/oil and gas upstream, midstream, downstream, chemical, power, marine, mining and general industry. Hawa Valves have ISO 9001. ISO 14000, OHSAS 18000, SIL 3, CE/PED, ATEX certified and have American Petroleum Institute monogram licenses of API 600, API 6A, API 6D, API 6DSS and API 609.

The dedicated in-house R&D facility is recognized by Government of India, Ministry of Science and Technology,

Department of Scientific and Industrial Research. Hawa Valves hold international patents.

“Hawa Valves India Pvt. Ltd. As a company is ready to meet all valves needs in any environment or filed” Likewise through a whole array of accomplishment including our vision, enthusiasm, flexibility, innovative product development and use of technology diversity of exports, emphasis on quality and shrewd business acumen indeed seems assured of a very bright future.

For more details: http://www.hawavalves.com/

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